Information Technology in Facilities Management - A Literature Review

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Information Technology in Facilities Management - A Literature Review

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ABSTRACT

Purpose: The aim of this paper is to present the state of the art of research in Information Technology (IT) in Facilities Management (FM).

Background: Initial studies indicate that investments into IT in FM often do not add the expected value, neither to the FM department itself nor to the organisation supported by the FM department. A basis for further research into this complex and inter-disciplinary area is therefore needed. This literature review will contribute to this basis.

Approach, Theory/Methodology: Based on a Systematic Literature Review (SLR) method, journal articles, with a focus on IT in FM were found. Relevant articles were organized in categories according to focus on 1. technology, 2. IT layer, 3. FM process, 4. theory and research method applied, and 5. type of findings. Finally research gaps were identified.

Results and practical implications: There seems to be a general belief in technology combinations as a way to speed up the rather slow IT diffusion process in FM. It is documented that current research into IT in FM has an unbalanced focus on few specific technologies, IT layers and FM processes, and that further research should focus more on the IT implementation process and use. Knowledge from implementation and use could be fed back into (and strengthen) conceptualization and development, thereby adding more value to FM.

Research limitations: The review is limited to the period 2008-2013. Only the search engine Scopus is used.

Originality/value: This is the first review paper focusing on IT in general in FM, giving an overview of the area and delivering a basis for further research.

Keywords

Facilities Management, Information Technology, ICT, Information Systems, Literature Review

1 INTRODUCTION

This paper presents current research with focus on Information Technology in Facility Management, published as journal articles since 2007.

Considerable resources are invested in implementing and using IT systems supporting FM work processes and activities. Initial studies indicate that these investments often do not add the expected value, neither to the FM department itself nor to the organisation supported by the FM department. A basis for further research into this complex and inter-disciplinary area is therefore needed. This literature review will contribute to this basis.

The systematic literature review (SLR) method used in this article is explained in section *2 Method*. In *3 Finding the Literature* the criteria for finding the literature and the approach using the search engine Scopus is explained. How data is extracted from the found literature is described in *4 Extracting data from the literature*. Data analysis is placed in section *5 Analysis of current research on IT in FM*

2 METHOD

This systematic literature review (SLR) is based on criteria in Okoli & Schabram (2010) supplemented by elements in Webster & Watson (2002). This SLR includes the following four stages including eight *steps*: Planning stage: *Purpose and goal*, Selection stage: *Searching the literature* + *Practical screening*, Extraction stage: *Quality Appraisal* + *Data Extraction* and Execution stage: *Analysis and Findings* + *Writing the Review*. This paper demonstrates the *Protocol* for this SLR, where only the author of this paper has been involved.

Based on a set of key words, identified through an initial snowball sampling, a broader search was conducted to find journal articles, with a focus on IT in FM. Relevant articles were grouped into categories according to focus on 1. technology, 2. IT layer, 3. FM process, 4. theory and research method applied, and 5. type of findings. The categories, which are based on an interpretation of the content in the articles, were listed in tables, thereby creating a basis for a quantitative and systematic analysis approach to the data extracted from the literature. Finally research gaps were identified.

3 FINDING THE LITERATURE

3.1 Search key words

To identify relevant IT related search key words, an initial search for articles published after 2007 within the area of IT in FM was conducted in the FM journal “Facilities”, using the search engine Scopus. For each article found with a focus on IT in FM, the author key words were added to the search string. This snowball sampling of search key words led to a search string, resulting in N=17 articles found. The search was done in title, author key words and indexed key words. The period chosen covering the last 6 years is found acceptable, taken the rapid development in IT into account.

Based on the above mentioned search string a final search was now done in all English journals, resulting in N=100 articles found. The search key words relating to FM were “Facilities Management” and “Facility Management”, the rest relate to IT. The search in “Facilities” N=17 and the search in all journals N=100 overlapped with N=5, thereby the total number of articles found was N=112. Data in Scopus about the articles were exported to an Excel spread sheet, where the screening and categorization was done.

3.2 Criteria for including literature

Abstracts in all N=112 articles found were now screened based on the following criteria: 1. Level of focus on IT in FM, 2. written in English language and 3. Journal articles. The articles were placed in one of three groups, primarily depending on their level of focus on the topic of IT in the operation phase of the facilities lifecycle. Articles with a main focus on the topic (N=32) were put in the first group, but also articles, with a content assessed to be of main relevance for

the topic, were put in this group. Articles with a minor focus on the topic (N=31), e.g. articles primarily focusing on the AEC phases were put in the second group. Finally articles with no focus on the topic (N=49) were placed in the third group. All N=32 articles in the first group are listed in Table 1, where technologies in focus in the articles are listed in columns, according to the technology area. See also section 5.1. Abbreviations used in Table 1 are explained in Appendix 1. Only articles shown in Table 1 are referred to in the following sections.

4 EXTRACTING DATA FROM THE LITERATURE

Only articles with a high relevance, as described above, were included in the next steps of the review. Each of these articles where downloaded from e.g. the publisher's web page, and stored in the reference manager software tool Mendeley. While reading printed paper versions of the articles, information, such as which technology each paper was focusing on, was typed in the spread sheet mentioned above in predefined columns. The spread sheet was then used for categorizing, synthesizing and analyzing the extracted data in the next steps.

5 ANALYSIS OF CURRENT RESEARCH ON IT IN FM

5.1 Technologies

Table 1 shows that each article, with one exception, has a focus on one or more specific information technologies, thereby placing each article in one or more technology areas (columns in Table 1). Fig. 1 is based on a simple count in the columns in Table 1 showing the number of articles with a focus within each of the technology areas. The area with most articles is Data Repositories N=21. Of these N=13 focus on BIM, making BIM the technology most often in focus in all the articles. The area with the next most articles is Sensor and Mobile N=15, and here the most common technologies are RFID tag systems N=6, followed by Augmented Reality and Virtuality N=4. The area with the third most articles is Interoperability N=11 with the BIM exchange standard IFC being the most common "technology" N=7, followed by exchange framework protocols N=6. Workflow Systems and Facilities Intelligence only receive attention in N=7 and N=7 articles.

Figure 1. Number of articles with a focus within each of the technology areas (An article can focus on more than one technology area)

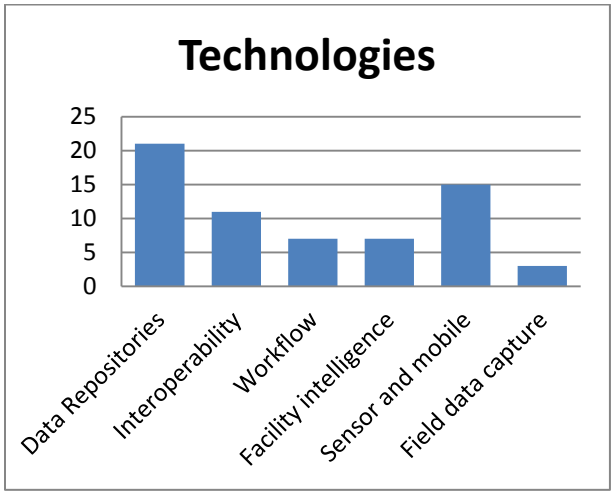


Table 1. Articles and technologies in focus. (Abbreviations according to Appendix 1.)

Articles	**L**	**Technology Focus**					
		Data Rep.	Inter-operab.	Work-flow	Facility Intell.	Sensor Mobile	Field capture
2014							
(Volk, Stengel, & Schultmann, 2014) **Review**	U	BIM	IFC COBie				
(Hou, Wang, & Wang, 2014)	C	Models				AR AV	
(Jung et al., 2014)	C	BIM					Laser scan.
(Hua, Göçer, & Göçer, 2014)	D	GIS			IB	Sensor	
(Irizarry, Gheisari, Williams, & Roper, 2014)	C	BIM				MAR	Drone
(Motamedi, Hammad, & Asen, 2014)	C	BIM	ICF	CMMS			
(Kriksciuniene, Pitner, Kucera, & Sakalauskas, 2014)	C	BIM	Protocols	CAFM	BMS BAS	CCTV	
(Scupola, 2014)	I	-	-	-	-	-	-
2013							
(Eadie, Browne, Odeyinka, McKeown, & McNiff, 2013)	U	BIM					
(Motamedi, Soltani, & Hammad, 2013)	C	BIM				RFID RTLS	
(Olbrich et al., 2013)	C	BIM	Protocols			AR	
(Kim, Wang, Love, Li, & Kang, 2013) **Review**	U	VR VE					
(Ko, Pan, & Chiou, 2013)	D	Database				RFID Web Tablets	
(East, Ph, Asce, Nisbet, & Liebich, 2013)	C	BIM	IFC MVD COBie etc.				
(Irizarry, Gheisari, Williams, & Walker, 2013)	D	BIM				AR	
(Chen, Hou, & Wang, 2013)	D	3D Database					
2012							
(Manzoor, Linton, Loughlin, & Menzel, 2012)	C				BMS BEMS	RFID PIR	
(Becerik-gerber, Asce, Jazizadeh, Li, & Calis, 2012)	I	BIM					
(Klein, Li, & Becerik-Gerber, 2012)	C	BIM					Photog ram. Laser scan.
2011							
(Lai & Yik, 2011)	U			CMMS			
(Motamedi, Saini, Hammad, & Zhu, 2011)	C	BIM	IFC			RFID	
(Hallberg, 2011)	C	Open BIM	IFC				
2010							
(Shen et al., 2010) **Review**	C	Objects	Protocols IFC			Web RFID VE VO	
2009							
(Elmualim & Pelumi-Johnson, 2009)	C			CAFM	IB BMS		
(Madritsch & May, 2009)	I			CAFM (ERP)			
(Bainbridge & Finch, 2009)	I			CAFM			
(Tulla, Vähä, Matinmikko, Tolman, & Möttönen, 2009)	C					RFID NFC SMS	
(Tolman & Parkkila, 2009)	C				IB	Sensors	
(Tolman, Matinmikko, Möttönen, Tulla, & Vähä, 2009)	C					Mobile techno.	
2008							
(Otto, 2008)	C		Protocols	CAFM	BAS		
(Vanlande & Nicolle, 2008)	C		IFC Protocols				
(Malatras, Asgari, & Baugé, 2008)	C	(BIM)	Protocols		BMS	WSN	

L: IT Layers**:** U: Use in practice, I: Implementation in Practice, D: Development, C: Conceptualization

5.2 Findings in the literature

The articles are grouped in Appendix 2.1-2.7 according to the technology area primarily in focus in each of the articles. Appendix 2.5 contains the largest group indicating a strong focus on Sensor and Mobile Systems. The second largest group is in Appendix 2.1, showing a strong focus on the Data Repositories technology BIM, but BIM is also included in articles in the other technology areas, making it the technology with the largest research focus in FM.

The findings in the articles indicate that IT in general is in the early stages of diffusion in FM organizations. CAFM or more specifically CMMS seem to be the only technology in focus that actually is being used in FM organizations (Madritsch & May, 2009) and (Lai & Yik, 2011). BIM is in the very early phases of implementation in FM, but acquiring the needed data seems to be a major obstacle (Becerik-gerber et al., 2012) and (Volk et al., 2014). Implementation of RFID technology in FM is also only just in the initial phase (Tulla et al., 2009).

The many articles dealing with conceptual ideas often including combinations of technologies indicate a belief in technology combinations as a way to ease the IT diffusion process. BIM could for instance have a greater potential when combined with other technologies such as VR or RFID (Kim et al., 2013) and (Shen et al., 2010), and combining MAR with BIM could support adoption of BIM in the FM domain (Irizarry et al. 2013).

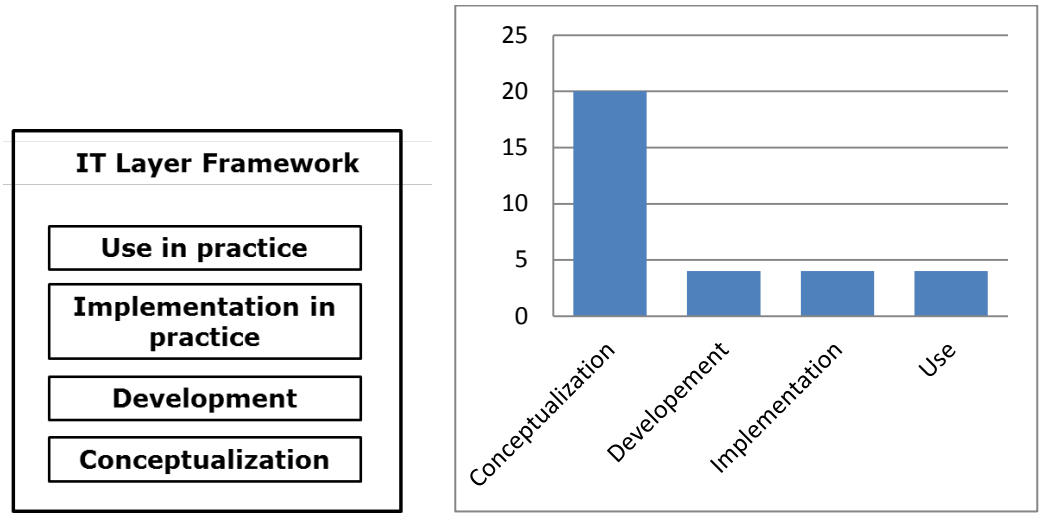
For the author of this paper, the focus on few specific future potential technologies in FM, e.g. BIM and RFID, seems surprising when experience from practice shows that other technologies such as GIS have progressed further in the diffusion process.

5.3 IT layer framework

The IT layer framework introduced in Fig. 2 and used in the second column in Table 2 is inspired by Kim et al. (2013) and should be understood as follows: Articles belonging to the "Conceptualization" layer gives ideas of how the IT in question will function, and can include a proof of concept; typically a test case or a questionnaire. In the "Development" layer articles focus on transforming ideas into something more tangible, e.g. software or hardware. This transformation is in the research field of software engineering characterized as implementation. In this paper the word implementation is used in relation to implementation of the IT solution into practice. Articles in the "Implementation in practice" layer are therefore concerned with the process of implementing IT in organizations. Articles in the "Use in practice" layer focus on how IT is used in organizations.

As seen in Figure 2, only 25% of the articles focus on implementation (N=4) and use (N=4) in organizations and 75% focus on conceptualization (N=20) and development (N=4). This indicates an unbalanced research focus. Much new knowledge could be gained if the focus was directed more toward FM organizations, where technologies are implemented and used. Such examples are; Becerik-gerber et al. (2012) who focus on BIM implementation, Madritsch & May (2009) who focus on implementation of CAFM systems, Scupola (2014) who focus on IT adoption and diffusion in FM organizations and Bainbridge & Finch (2009) who focus on CAFM as a tool for knowledge management. Knowledge from implementation and use could be fed back into (and strengthen) conceptualization and development. Upcoming technology combinations, e.g. BIM used as a basis for AR, may need more conceptualization and development before being introduced to the FM organizations.

Figure 2. The IT Layer Framework and the Number of articles with a focus within each of the IT Layers (Each article is only placed in one layer)



5.4 FM processes and activities

In Table 2 the focus of each article in relation to FM processes, activities and tasks is specified. Maintenances seems to be the only specific FM activity in focus in the articles N=12. The more general concept of Asset Management, which can also include Maintenance, is in focus in N=8 articles. Other FM activities, such as Space Management, seem to be neglected. Information Management (including Decision Making and Knowledge Management) is the most dominant issue N=17. Building Performance, including User Satisfaction and Climate Control has focus in N=5 articles. AEC-FM, including design, construction and handover procedures from AEC to FM and vice versa is in focus in N=5 article. A typical conceptual article in this group is East et al. (2013), who are proposing an IFC based handover method from the AEC phases to FM. Data Creation and Capturing for FM purposes is in focus in N=3 articles.

5.5 Theory and research methods

Most of the findings presented have a prescriptive nature N=21. Typically a model or a method is proposed. The rest of the articles present descriptive findings N=7, diagnostic N=2, and predictive N=2. See Table 2.

A majority of the articles N=24 include conceptual solutions (e.g. methods) and often include empirical data from survey questionnaires N=10, case studies N=2 and test cases or scenarios N=10, see Table 2. Some of the conceptual solutions are not evidence based, but based on the authors own knowledge, experience and ideas. All studies including questionnaires and case studies are cross-sectional. One exception is Lai & Yik (2011) who study CMMS data covering a 12 month period of maintenance in a Hotel. In general each article only uses one method for data collection and analysis, e.g. quantitative, qualitative (survey or case study) or conceptualization, but in some of the articles the choice of method is not clearly stated. The studies are sometimes based on vague presumptions, e.g. that RFID technology can improve a specific FM process. The only article presenting a study of data from a technology actually in use in an FM organization is Lai & Yik (2011). Using statistical methods they analyze historical data from a CMMS representing 12 month corrective maintenance work.

Table 2. Focus of articles in relation to IT Layers, FM processes and Research Methods

		FM processes, activities and tasks								**Research Methods**					
	IT Layer	Maintenance	Information Management	Asset Management	Building Performance	AEC-FM	Data Creation / Capturing	FM supply chain	Emergency Management	Survey Questionnaire (x) Interviews	Case Study	Conceptual /Development	Quantitative	Test Case or Scenario	**Findings**
Count:		12	17	8	5	5	3	1	1	10	2	24	7	10	
2014															
(Volk et al., 2014) **Review**	U	x				x				-	-	-	-	-	DS
(Hou et al., 2014) (Review)	C	x	x									x			PS
(Jung et al., 2014)	C	x				x	x					x		x	PS
(Hua et al., 2014)	D				x					x		x	x		PS
(Irizarry et al., 2014)	C	x	x									x		x	PS
(Motamedi et al., 2014)	C			x								x		x	PS
(Kriksciuniene et al., 2014)	C	x			x							x		x	PS
(Scupola, 2014)	I							x		(x)					DN
2013															
(Eadie et al., 2013)	U	x				x				x			x		DS
(Motamedi et al., 2013)	C			x								x	x	x	PS
(Olbrich et al., 2013)	C		x									x			PS
(Kim et al., 2013) **Review**	U									-	-	-	-	-	PD
(Ko et al., 2013)	D	x										x		x	PS
(East et al., 2013)	C		x			x						x			PS
(Irizarry et al., 2013)	D	x	x							x		x	x		PS
(Chen et al., 2013) (Review)	D	x										x			PS
2012															
(Manzoor et al., 2012)	C				x							x		x	PS
(Becerik-gerber et al., 2012)	I		x							x		x			PS
(Klein et al., 2012)	C		x				x					x	x	x	DN
2011															
(Lai & Yik, 2011)	U	x	x				x				x		x		PD
(Motamedi et al., 2011)	C		x	x					x			x		x	PS
(Hallberg, 2011)	C	x										x			PS
2010															
(Shen et al., 2010) **Review**	C		x			x				-	-	-	-	-	DS
2009															
(Elmualim & Pelumi-Johnson, 2009)	C	x			x					x			(x)		DS
(Madritsch & May, 2009)	I		x	x						x	x	x			PS
(Bainbridge & Finch, 2009)	I		x							x					DS
(Tulla et al., 2009)	C		x	x								x		x	DS
(Tolman & Parkkila, 2009)	C		x	x	x							x			PS
(Tolman et al., 2009)	C		x	x						(x)		x			DS
2008															
(Otto, 2008)	C				x					x		x			PS
(Vanlande & Nicolle, 2008)	C		x									x			PS
(Malatras et al., 2008)	C		x	x								x			PS

IT Layers: U: Use in practice
I: Implementation in Practice
D: Development
C: Conceptualization

Findings: PS: Prescriptive (How can we make it happen?)
PD: Predictive (What will happen?)
DN: Diagnostic (Why did it happen?)
DS: Descriptive (What happened?)

5.6 Chronology

The focus on BIM starts in 2011 and has been unbroken since (Table 1). Being a BIM data drop concept, it is not surprising to see a focus on COBie starting in 2013; two years after BIM came in focus. Also in 2013 focus on Augmented Reality (AR) starts. The focus on other technologies such as IFC, CMMS/CAFM, BMS and RFID has been evenly distributed since 2008, but none ever as intense as with BIM. Other technologies used in practice already, such as GIS, could get more focus, if more studies focus on implementation and use.

5.7 Journals and their research scope

The research field/scope of each journal, where the articles are published, is mapped in Appendix 3. The journals are mainly within the research fields of Information Systems (IS), Computer Science, Management, Construction Engineering and Facilities Management. It is not surprising to find "IT in FM" articles in IS and Computer Science Journals, likewise it is not surprising to find them in Management and FM journals. In a lifecycle perspective FM can be regarded as closely linked to Construction Management, which can explain why articles on IT in FM also are found in journals in the Construction research field.

6 CONCLUSION

This review shows that 75% of the articles have a focus on conceptualization and development while only 25% focus on implementation and use in organizations. Most of the findings presented have a prescriptive nature. This indicates an unbalanced research focus. Much new knowledge could be gained if focus shifted towards FM organizations, where technologies are being implemented and used. Knowledge from implementation and use could be fed back into and strengthen conceptualization and development, thereby adding more value to FM. Upcoming technology combinations, e.g. BIM used as a basis for AR, may need further conceptualization and development before being introduced to the FM organizations.

The technologies most in focus are BIM, followed by RFID. Most of the articles focus on combinations of different technologies, indicating a general belief in technology combinations as a way to speed up the rather slow IT diffusion process in FM. Other technologies used in practice already, such as GIS, would probably get more into focus, if more studies focused on implementation and use in practice.

Some of the conceptual solutions presented are not evidence based, but seem to rely on the authors own knowledge, experience and ideas. The choice of method is often not clearly stated in the articles. The studies are sometimes based on vague presumptions e.g. that RFID technology can improve a specific FM process.

The suggested IT solutions are most often aimed at supporting Information Management in FM, followed by Maintenance and Asset Management. Some common FM activities, such as Space Management, seem to be neglected.

Findings in the articles indicate that IT in general is in its early stages of diffusion into FM organizations.

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APPENDIX 1: ABBRIVATIONS

Technology Area	Abbreviation	Full / Expanded
Data Repositories / Containers / Viewers	DBMS	Database Management System
	BIM	Building Information Modeling
	VR	Virtual Reality
	VE	Virtual Environment
	GIS	Geographic Information System
Interoperability	IFC	Industry Foundation Classes
	COBie	Construction Operations Building Information Exchange
	MVD	Model View Definition
Workflow Systems	ERP	Enterprise Resource Planning
	IWMS	Integrated Workplace Management System
	CAFM	Computer-Aided Facility Management
	CMMS	Computerized Maintenance Management System
Facilities Intelligent Systems	BAS	Building Automation System
	BMS	Building Management System
	IB	Intelligent Buildings
	BEMS	Building Energy Management System
	LAN	Local Area Network
	Wi-Fi	Local Area Wireless Network
	RFID	Radio-Frequency Identification
	CCTV	Closed-Circuit Television (or video surveillance)
	AR	Augmented Reality
	AV	Augmented Virtuality
	MAR	Mobile Augmented Reality
	RTLS	Real-Time Location System
	PIR	Passive Infrared
	VO	Virtual Organization
	NFC	Near Field Communication
	SMS	Short Message Service
	WSN	Wireless Sensor Network
	Web	World Wide Web
	VE	Virtual Environment

APPENDIX 2.1 – 2.7: ARTICLES GROUPED ACCORDING TO TECHNOLOGY AREA

Appendix 2.1 Method, Focus and Findings for **Data Repository** related articles.

Article	**Method**	**Focus**	**Findings**
Becerik-gerber et al. (2012)	Conceptual. Implementation recommendations based partly on a questionnaire in 103 organizations in USA	BIM implementation	FM organizations are implementing BIM. Identifies requirements for implementing BIM.
Eadie et al. (2013)	Statistical analysis of results from a survey questionnaire	Use of BIM in the AEC-FM phases	BIM is used most often in the early stages and less in the later stages of the AEC-FM process
Volk et al. (2014)	Review	Implementation, use and research of BIM in existing buildings in the maintenance and deconstruction lifecycle stages	Limited implementation of BIM in existing buildings. Challenges are 1. automation of data capture and BIM creation, 2. update and maintenance of information in BIM, 3. handling and modeling of uncertain data objects and relations occurring in existing buildings in BIM
Kim et al. (2013)	Review	Virtual Reality (VR) and Virtual Environment (VE) in the built environment	VR, especially combined with BIM, will become a very effective tool in early design conception in the area of FM.
Chen et al. (2013)	Development	Develop a system for accessing maintenance data from a 3D model	
(Hua et al. (2014)	Development	GIS used to map indoor survey results of building occupant satisfaction (No other article study the use of GIS in FM)	

Appendix 2.2 Method, Focus and Findings for **Interoperability** related articles.

Article	**Method**	**Focus**	**Findings**
Shen et al. (2010)	Review	Data (IFC) and framework (protocols) interoperability, system integration approaches and management of AEC/FM processes using project management and change management	Research opportunities, e.g.: Integration of construction project lifecycle information to support management and maintenance of built structures, facilities, and infrastructures. One example is integration of BIM and RFID
Hallberg (2011)	Conceptual	Discusses IFC and BIM as a basis for a lifecycle FM system	
Vanlande & Nicolle (2008)	Conceptual	IFC and protocols to share information between different lifecycle phases. Describes a conceptual 3D data repository.	
Malatras et al. (2008)	Conceptual	propose a network and protocol architecture for integrating different technologies relevant to FM	
East et al. (2013)	Conceptual	Proposes an AEC-FM handover IFC based methodology	

Appendix 2.3 Method, Focus and Findings for **Workflow Systems** related articles.

Article	**Method**	**Focus**	**Findings**
Bainbridge & Finch (2009)	Survey questionnaire in more than 100 organizations	The role of CAFM as a tool for knowledge management in FM organizations in Scotland	Half the organizations are considering to use or are using CAFM. Many issues to tackle before all relevant stakeholders can contribute with data and benefit from data.
Madritsch & May (2009)	Case studies. Interviews in case organizations and with market players	Implementation of CAFM in FM organizations in the German speaking countries	Propose a process model for implementation of CAFM systems
Lai & Yik (2011)	Statistical analysis of historical data from a CMMS representing 12 month	Efficiency of corrective maintenance work in a Hotel	With higher utilization levels of manpower, the efficiency of corrective maintenance decline
Motamedi et al. (2014)	Conceptual	Proposes a model for using BIM as the central database for a CMMS system for supporting failure root cause detection in facilities	

Appendix 2.4 Method, Focus and Findings for **Facility Intelligence Systems** related articles.

Article	**Method**	**Focus**	**Findings**
Elmualim & Pelumi-Johnson (2009)	(Conceptual) 15 survey respondents	Understanding of the concept Intelligent Buildings (IB) and CAFM and their potentials for effectiveness of FM functions	No common or fixed definition of IB and one third of the respondents do not believe CAFM system is vital for FM effectiveness
Otto (2008)	(Conceptual) Survey, including 450 office users, with a focus on user influenced energy consumption	Standardization and conceptualization of dataflow between Building Automation Systems (BAS) and CAFM using open exchange standards	Proposes a concept for a knowledge based service system, giving users access to monitor and influence the heating and the cleaning in their office

Appendix 2.5 Method, Focus and Findings for **Sensor and Mobile Systems** related articles.

Article	**Method**	**Focus**	**Findings**
Manzoor et al. (2012)	Test case	Occupancy monitoring with RFID-based "gateways" installed at entrance doors is proposed. The occupancy monitoring is fused with data from Passive Infrared sensors and used to control indoor lighting system.	13% can be saved on electricity using the approach
Tulla et al. (2009)	(Conceptual) Test cases using RFID to support FM processes, e.g. cleaning.	Diffusion of RFID with NFD in FM.	SMS is heavily used in FM and that the use of RFID in FM is in an infant stage
Tolman et al. (2009)	(Partly conceptual) Interviews	FM personnel's perceived benefits and obstacles,	Technology related problems often hinder the integration of

		concerning adopting sensor and mobile technologies	mobile applications to existing IT systems within the company. Mobile phones are preferred over palm top devices
Hou et al. (2014)	Conceptual	Suggest a conceptual model for using 3D models as basis for AV/AR on handheld devises	
Irizarry et al. (2014)	Development	Suggest BIM as a basis for AR combined with the use of drones, to support decision process in FM operations	
Olbrich et al. (2013)	Conceptual	Suggests a system including BIM and AR, where the users on site have access to key information about facilities	
Irizarry et al. (2013)	Conceptual	Usability of MAR based on BIM in different scenarios involving participants	
Motamedi et al. (2013)	Conceptual	Explores the possibilities of using RFID tags attached to assets for localization purposes. Localization data in the BIM model is transferred to the RFID tags	
Motamedi et al. (2011)	Conceptual	Describes a method for storing and sharing role based data, for different stakeholder involved in the assets lifecycle, on RFID tags attached permanently to the assets. Data can be accessed by all stakeholders using a BIM model	
Ko et al. (2013)	Development	Propose a method for communication between RFID tags and a web based maintenance system	
Tolman & Parkkila (2009)	Conceptual	Show interactive use of different sensor systems to control building conditions and the well-being of the occupants	

Appendix 2.6 Method, Focus and Findings for **Field Data Capture Systems** related articles.

Article	Method	Focus	Findings
Klein et al. (2012)	Conceptual. Methods are compared to laser scanning technics.	Photogrammetry (image based) and manual methods for capturing geometry used as an aid to verify existing as-built BIM models, and to establish as-built BIM	Image based method is in some cases not accurate enough according to the standards
Jung et al. (2014)	Conceptual. Test case using real buildings	Develop a method for capturing data for creation of as-built BIM using point cloud scanning	

Appendix 2.7 Method, Focus and Findings for articles related to **technology areas in general**.

Article	Method	Focus	Findings
Scupola (2014)	Interviews in 12 organization	Organizational, technological and environmental drivers and barriers to IT adoption and diffusion in FM organizations in Denmark	Presents a theoretical supply-chain framework
Kriksciuniene et al. (2014)	Conceptual	How "Leading" data from e.g. sensors and "lagging" cost and energy consumption data can be handled in a system combining e.g. BIM, CAFM and sensors	

APPENDIX 3: NUMBER OF ARTICLES PER JOURNAL AND RESEARCH FIELDS OF THE JOURNALS

		Research fields							
	Number of articles per journal	Information Systems	Computer science	Management	Construction Engineering	Facilities Management	Building Science	Design Engineering	Other
Number of journals within the research field:		6	6	4	4	3	2	2	5
Facilities	7					X			
Automation in Construction	6	X		X	X			X	
Advanced Engineering Informatics	3	X	X						
Journal of Information Technology in Construction ITcon	2	X			X	(X)			
Journal of Computing in Civil Engineering	1	X	X						
Journal of Construction Engineering and Management	1	(X)		X	X				
Building and Environment	1						X		X
Visual Computer	1		X						X
Structure and Infrastructure Engineering	1					X			
International Journal of RF Technologies	1								X
Building Services Engineering Research and Technology	1						X	X	
Journal of Global Information Technology Management	1	X							
Proceedings of the IEEE	1		X						
International Journal of Computer Science and Applications	1		X						
IEEE Systems Journal	1		X						
International Journal of Product Lifecycle Management	1			X					X
International Journal of Environment and Pollution	1								X
Journal of Construction Engineering and Management	1			X	X				